Sole

APPLICATION
FOR
UNITED STATES LETTER PATENT

TO THE ASSISTANT COMMISSIONER FOR PATENTS:

BE IT KNOWN, that I, **Howard B. Sosin** has invented certain new and useful improvements in **SYSTEM FOR OPTIMIZATION OF GOLF CLUBS** of which the following is a specification:

System for Optimization of Golf Clubs

Field of the Invention

The present invention relates to a system for constructing a set of matched golf clubs which are optimized for a particular golfer.

Background of the Invention

Sub A7

The rules of golf allow a golfer to carry a golfer to carry a maximum of fourteen clubs: an assortment of "woods" and "irons," and usually one "putter." Golfers select clubs to produce shots of predetermined lengths (carry plus roll) and trajectories. Once clubs have been selected, the golfer's goal is to swing each club in a manner that gives predictable results. It is recognized that the golfer's job is made easier if the same (or a similar) swing works for all clubs: a "repeatable" swing. It is further recognized that a repeatable swing is facilitated by having all of the clubs "feel the same" (or similar) during the swing. A set of clubs which feel the same to the golfer is said to be "matched."

Club manufacturers offer a vast array of clubs for golfers to choose from. Within a set, manufacturers typically seek to match clubs (often separating woods and irons) by having the club heads have similar shape and be made of similar materials. Additionally, sets usually have uniform grips and shafts (material and flexibility) and some manufacturers allow the golfer to customize club length and/or lie.

In addition to matching these basic parameters, many attempts have been made to match clubs in other ways. "Swing weighting" systems generally match clubs according to their first inertial moment about an arbitrarily selected point twelve inches ("Lorythmic scale") or fourteen inches ("Official scale") from the butt end of the club (see, U.S. Patent Nos. 4,128,242 to Elkins, Jr. and 4,887,815 to Hughes *et al.*). Related systems have been proposed to balance the club about a point closer to the grip, *e.g.*, five inches from the butt end of the shaft (see, U.S. Patent No. 4,674,324 to Benoit). Other methods include matching the first inertial moment and/or the second inertial moment

(see, U.S. Patent No. 4,415,156 to Jorgensen), the radius of gyration (see, U.S. Patent Nos. 4,674,324 to Benoit and 5,277,059 to Chastonay), or the vibrational frequencies (see, U.S. Patent Nos. 4,555,112 to Masghati and 5,722,899 to Cheng) over the set of clubs.

With the exception of one system that seeks to equalize the dynamic moment of inertia of the club including the moment of inertia of the golfer's arms (see, U.S. Patent No. 5,769,733 to Williams, *et al.*), all currently known club matching systems focus on matching clubs to a selected mathematical standard with no attempt to incorporate the physical and swing characteristics of a particular golfer. Since golfers differ in many ways not addressed by mathematical standards, it is not surprising that it remains an elusive goal for a golfer to obtain a set of clubs which truly provide him with a uniform swing feel. An improved method of selecting and matching clubs to optimize a golfer's game is needed.

Summary of the Invention

The present invention provides a method of designing a matched set of golf clubs which takes into account both objective parameters which control the motion of the ball in response to an impact from a club head, and subjective parameters related to individual preferences in "feel" and idiosyncracies of a particular golfer's swing.

In one aspect, the invention comprises a method of designing a golf club, comprising detemining relationships relating tempo (how fast the golfer swings) and perceived force (how much force is applied along the shaft) to club length and club head mass for a particular golfer. Two parameters are selected from the following group of three: target distance, club length (and shaft flexibility), and preferred trajectory for the ball, and then these parameters are used with the tempo and perceived force functions to determine the third parameter and the club head mass for the golf club design. Tempo may be measured by the speed of the golfer's hands at the moment of impact, and perceived force by the centripetal force along the shaft of the club at the moment of impact. In order to determine these values, an effective arm length may be determined, for example by measuring the actual arm length of the golfer, or the distance from the

golfer's hands to his sternum or collarbone in address position. Trajectory may be controlled by varying the club head loft, which may be the design loft (*i.e.*, manufacturer's intended loft) or the effective loft (*i.e.*, impact loft). Exemplary functions for tempo and perceived force with club length (or club length plus arm length) include constant, linear, or power-law relationships. The method may comprise designing multiple clubs fitting the tempo and perceived force functions. One or more of the clubs may be weighted in order to reduce the variation in perceived length over the multiple clubs. Perceived length may be determined by the radius of gyration around a selected center point, which may be determined as described below. A club design method according to this aspect of the invention may include designing a set of up to thirteen golf clubs, all of which obey selected tempo and perceived force functions and having reduced variation in perceived length over the set. The method may further include constructing the clubs, using, for example, a CAD/CAM system.

In another aspect, the invention includes a method of determining the personal center of gyration of a golfer, by having the golfer swing a test club and a weighted comparison club. First the golfer swings the test club to feel its perceived length. Then the golfer swings a comparison club one or more times, while weight is added to the comparison club at a selected point on the shaft, until the clubs feel as though they have the same club length to the golfer. The point around which the test club and the weighted comparison club have the same radius of gyration is then determined. This aspect of the invention further includes constructing a plurality of clubs having reduced variation in their radii of gyration around the center point determined according to this method.

In a further aspect, the invention includes a matched set of clubs (or a subset) for a golfer. Each club of the matched set has a target distance (or preferred trajectory) and a club length, and the tempo of the clubs when swung by the golfer to achieve the target distances has a selected functional relationship to the club length (the relationship should actually constrain the club design). The functional relationship may be, for example, constant, linear, polynomial, or power-law. In a related aspect, the invention comprises a matched set of golf clubs which have a selected relationship between perceived force and club length when swung to achieve a set of target distances (or preferred trajectories).

Perceived force may be determined by the centripetal force applied along the shaft at impact, and the tempo may be determined by the speed of the golfer's hands at impact. Preferably, clubs have selected functional relationships for both tempo and perceived force. Clubs may further have optimized lean angle as described in U.S. Patent Application 08/248,515. Clubs may be constructed, for example, using a CAD/CAM system.

As it is used herein, the term "club length" means the length of a club as measured from the butt end of the shaft to the center of mass of the club head.

Brief Description of the Drawing

Preferred embodiments of the invention are described with reference to the single figure of the drawing, which

Figure 1 plots of club head mass as a function of club length for three sets of clubs according to the invention; and

Figure 2 is a schematic view of a club weighted to adjust the radius of gyration according to the invention.

Detailed Description

A logical starting point (although not the only possible starting point) in the design of a set of clubs is for the golfer to specify target distances (carry and roll) and trajectories for up to 13 clubs (leaving one space in the set for a putter) that he could expect to achieve with reasonable consistency with a full swing given his physical parameters and swing characteristics. Thus, for example, a reasonably advanced golfer might specify target distances of 250, 225, 200, 187.5, 175, 162.5, 150, 137.5, 125, 112.5, 100, 87.5, and 75 yards, respectively. He could also specify desired trajectories. In the preferred embodiments of the invention, desired trajectory is fully described either by the design loft of the club head (the manufacturer's intended loft), or by the effective loft of the club head (the actual loft at impact) each as more fully defined in copending

and commonly assigned U.S. Patent application 09/248,515, filed February 8, 1999, which is incorporated herein by reference.

For a particular type of golf ball, each target distance can be achieved by an infinite number of combinations of club head masses and lofts, club lengths and shaft flexibilities, and swing speeds. A table (hereinafter, the Table) could be constructed that, to any degree of fineness desired, shows how varying these parameters varies the distance (and trajectory) achieved. An automatic ball striking machine could be used to construct such a Table. Alternatively, the Table could be constructed by carefully observing the results of golfers hitting balls with various clubs. In yet another embodiment, the values in the Table might be determined by analytical calculations.

A golfer may wish to base his target distances and trajectories off the longest distance he can consistently achieve (typically with a driver). Conventional wisdom suggests that driving distance is relatively insensitive to club head weight for most golfers (see, for example, Cochran and Stobbs, *Search for the Perfect Swing*, Triumph Books, Chicago, 1968). Therefore, club head weight can be held at a suitable constant level (*e.g.*, 200 g) while optimizing club length (and shaft flex) and club head loft. Alternatively, the player may be allowed to vary club head weight in the following procedure in order to determine a maximum driving distance.

Using drivers of varying length (and possibly also of varying shaft flexibility), the length which allows the golfer to generate the maximum club head speed (where, *ceteris paribus*, speed is a surrogate for impact force) can be determined using various known devices for the measurement of club head speed at impact. Once the maximum consistently achievable club head speed is known, the other parameters (*e.g.*, loft, club head weight, *etc.*) can be varied (using analytical or empirical methods, or by having a golfer attempt to swing the club at a constant speed) to determine the combination of parameters that achieves the golfer's maximum driving distance. Knowing his maximum driving distance would allow a golfer to choose useful target distances for the remaining clubs.

The present invention suggests that two parameters should be used to select amongst possible clubs for each desired target distance and trajectory: the force the golfer

wants to feel at the time he strikes the ball with the club (his "perceived force" function), and how fast he wants to swing the club (his "tempo" function). The invention further teaches that a golfer will be better able to achieve a repeatable swing (*i.e.*, generate the desired perceived force at the desired tempo over and over again) if the variation in how long different clubs feel during the swing (the "perceived length" function) is reduced relative to prior art clubs. In the preferred embodiments of the invention, perceived force is measured by the centripetal force at the point of impact of the club head with the ball, and tempo is measured by the speed of the golfer's hands (also at the point of impact). In other preferred embodiments of the invention, perceived length is measured by the radius of gyration calculated around a golfer's personal center (described below).

In one preferred embodiment of the invention, tempo and perceived force are maintained as constants over the set of clubs. This embodiment has been found to lead to club heads that are lighter than those usual in the art. In another preferred embodiment, tempo increases linearly with club length plus arm length over the set of clubs, while perceived force remains constant. The motivation for this preferred embodiment comes from the fact that many golfers swing their longer clubs (for longer shots) with more abandon (*i.e.*, faster) than their shorter clubs, and thus prefer to feel a faster hand speed for the longer clubs, while retaining the same feeling of force at impact. This embodiment has been found to lead to club heads that are heavier than those usual in the art. An embodiment wherein tempo is constant and centripetal force increases linearly with length produces constant weight club heads; an embodiment wherein tempo is constant and centripetal force increases faster than linearly produces club heads that increase in weight as the club length increases. Finally, an embodiment wherein tempo increases with the square root of club length plus arm length, while perceived force remains constant, maintains the ability of the golfer to swing longer clubs with greater abandon, and produces club heads with weights similar to those of prior art clubs.

The first two preferred embodiments described in the paragraph above can be considered to be zero-parameter and one-parameter models of a golfer's preferred swing characteristics. Higher-order models can also be used, *e.g.*, polynomial or power-law models. The model chosen will depend upon the preferences of the individual golfer, and

may be determined subjectively or analytically, for example, by video analysis of the golfer's swing to determine a preferred relationship between hand speed, centripetal force, club length, and club head mass. The number of parameters should be small enough to actually constrain the club selection.

Regardless of the swing technique used by the golfer, at impact the left (leading) arm and the shaft of the club typically will be virtually in line and moving together like an extended shaft. This fact allows determination of the speed of the golfer's hand at impact (the tempo) if his "effective" arm length is known. (The effective arm length may be approximated by the actual length of the golfer's arms, or by a length measured from the top of the sternum to the hands when the club is at address position, or by other appropriate measurements of the golfer's body). That is, knowing the impact speed of two club heads (*e.g.*, the driver and another club), the lengths of the clubs and the golfer's effective arm length allows the calculation of hand speed and centripetal force for each club at impact, using the following equations:

$$v_{hand}(driver) = v_{driverhead} \frac{\ell_{arm}}{\ell_{driver} + \ell_{arm}} \tag{1}$$

$$v_{hand}(club) = v_{clubhead} \frac{\ell_{arm}}{\ell_{club} + \ell_{arm}} \tag{2}$$

$$F_{cent}(driver) = m_{driverhead} \frac{v^2_{driverhead}}{\ell_{driver} + \ell_{arm}} \tag{3}$$

$$F_{cent}(club) = m_{clubhead} \frac{v^2_{clubhead}}{\ell_{club} + \ell_{arm}} \tag{4}$$

where $v_{hand}(driver)$ and $v_{hand}(club)$ represent the speed of the hands when swinging the

driver and the second club, respectively, ℓ_{arm}, ℓ_{driver}, and ℓ_{club} represent the golfer's effective arm length and the lengths of the driver and the second club, respectively, $v_{driverhead}$ and $v_{clubhead}$ represent the velocities at impact of the driver head and the second club head, respectively, and $m_{driverhead}$ and $m_{clubhead}$ represent the masses of the driver head and the second club head, respectively. In this embodiment, centripetal force is calculated based only on the contribution due to the mass of the club head (justification for this assumption can be found, for example, in Cochran and Stobbs, *Search for the Perfect Swing*, p. 145-147, which suggests that at impact the club head can be modeled as being suspended from a length of string). More rigorous computations of centripetal force will be readily apparent to those skilled in the art.

Using the model to determine r_{tempo} and r_{force} (the ratios of hand speed and centripetal force of the two clubs), and solving for the mass of the club head (for a specified club length), we calculate

$$r_{tempo} \equiv \frac{v_{hand}(club)}{v_{hand}(driver)} = \frac{v_{clubhead}}{v_{driverhead}} \frac{\ell_{driver}+\ell_{arm}}{\ell_{club}+\ell_{arm}} \tag{5}$$

$$r_{force} \equiv \frac{F_{cent}(club)}{F_{cent}(driver)} = \frac{m_{clubhead}}{m_{driverhead}} \left(\frac{v_{clubhead}}{v_{driverhead}}\right)^2 \frac{\ell_{driver}+\ell_{arm}}{\ell_{club}+\ell_{arm}} \tag{6}$$

$$m_{clubhead} = m_{driverhead} \frac{r_{force}}{r_{tempo}^2} \left(\frac{\ell_{driver}+\ell_{arm}}{\ell_{club}+\ell_{arm}}\right) \tag{7}$$

A number of possible models for the variation of r_{tempo} and r_{force} with club length and/or club mass are contemplated. Exemplary models include linear relationships (*e.g.*, $r_{tempo} = \ell_{club}/\ell_{driver}$ or $r_{tempo} = (\ell_{club}+\ell_{arm})/(\ell_{driver}+\ell_{arm})$), polynomial relationships (*e.g.*, $r_{tempo} \propto (\ell_{club}/\ell_{driver})^2 + c_0 (\ell_{club}/\ell_{driver})$), and power-law relationships (*e.g.*, $r_{tempo} = (\ell_{club}/\ell_{driver})^k$ or $r_{tempo} = (\ell_{club}+\ell_{arm}/\ell_{driver}+\ell_{arm})^k$). In particular, a square root relationship in which $r_{tempo} =$

$((\ell_{club}+\ell_{arm})/(\ell_{driver}+\ell_{arm}))^{1/2}$ and $r_{force} = 1$ has been found to give excellent results for the inventor. **Figure 1** shows relationships between club head mass and club length for the cases of $r_{tempo} = r_{force} = 1$ **(20)**, $r_{tempo} = (\ell_{club}+\ell_{arm})/(\ell_{driver}+\ell_{arm})$ and $r_{force} = 1$ **(22)**, and $r_{tempo} = ((\ell_{club}+\ell_{arm})/(\ell_{driver}+\ell_{arm}))^{1/2}$ and $r_{force} = 1$ **(24)**. (In this Figure, points represent individual clubs, and the line represents the ideal functional relationship, assuming an arm length of 33" for the golfer).

For example, suppose a golfer with a 33" arm length chooses a 48" driver and a 214 gram club head. If he chooses a 36" wedge, and desires constant centripetal force, the club head weights he would use in the constant, linearly increasing, and square root relationships between hand speed and club length plus arm length would be 251, 346 and 295 grams, respectively. The golfer would complete the wedge design by going to the Table at the target distance and choosing the loft that, when combined with the calculated club head mass, club length (and shaft flexibility), and club head speed, produces the target distance for the wedge. Alternatively, the golfer could specify the desired loft (*i.e.*, trajectory) of the wedge instead of its club length. The Table could once again be used to solve for the missing parameter that satisfies the target distance while maintaining the desired tempo and perceived force.

It will be understood by those skilled in the art that the selected relationships between tempo, perceived force, and club length may not be constant over an entire set of clubs. For example, different relationships may obtain over the irons and the woods, or over other subsets of a full set of clubs, without departing from the principles of the invention.

Further optimization may also be applied to some or all of a set of clubs whether or not they have been optimized as described above. For example, the lean angles of the clubs may be adjusted to equate the effective lofts and the design lofts, as described in copending and commonly assigned U.S. Patent Application 09/248,515, filed February 8, 1999, which is incorporated herein by reference. In addition, further optimization may be achieved by reducing the variation of the perceived length of the set or subsets of clubs, as described below.

In one preferred embodiment, perceived length is approximated by the radius of gyration (ROG). There are many plausible centers around which ROG can be measured for the purpose of matching a set of clubs, ranging from the shoulder to the elbow to the wrist to points on the shaft of the club. Previous patents (*e.g.*, U.S. Patent No. 5,277,059 to Chastonay) have used particular centers for these calculations, but in each case the center point was assumed to be the same for all golfers. The golf swing is a complex muscular action with many moving parts that must be carefully coordinated and sequenced. It is therefore not surprising that prior art, with its arbitrarily selected center of ROG, has not produced a matching system in which "matched" clubs feel substantially the same for all golfers. The present invention encompasses the realization that the center of the ROG may be a function of the swing style of a particular golfer, and that a personalized center can be measured for each golfer and used for further optimization and club matching. That is, it is believed that it is beneficial to dynamically match a set of clubs by reducing the variation in or equating their ROGs around the golfer's personal center, and further that it is beneficial for the ROG to be quite short, as compared to that of conventional clubs. These aims can be accomplished in an embodiment of the invention as follows.

First, a golfer swings his shortest club (*e.g.*, a wedge), and mentally notes its feel. He then swings a relatively long club (*e.g.*, a driver), and weight (*e.g.*, lead tape) is added at a specified point along the shaft of the driver (usually below where the hands grip the club, relatively close to where the grip ends) until the two clubs feel as though they are the same length when swung. (The two clubs used in this test will preferably but not necessarily have been optimized for tempo and perceived force as described above). Using the magnitude of the added weight, the center of the ROG can be determined analytically, by constructing an equation for the ROG for each club about an unknown center point X. The ROG of the two clubs can then be set equal to solve for X, the golfer's personal center. All remaining clubs in the set can then be weighted so as to equate the ROG to that of the two measured clubs. Alternatively, clubs may be weighted to equate ROG only across subsets of the clubs. A club **10** weighted to adjust the ROG is shown in **Figure 2**. The weight **12** is placed on the shaft **14** of the club **10**. The origin at

the butt end of the shaft O, arbitrary position X (positive, as shown), the weight **12** position p_{weight}, and the length of the club ℓ_{club} are all shown.

It should be noted that golfers are often not used to thinking in terms of perceived length, and steps should be taken to explain the perceived length concept so that the golfer can accurately identify clubs having the same perceived length. It may be useful to have the golfer swing prior art (*i.e.*, unweighted) clubs, for example a wedge and a driver, and to identify the difference in feel as a difference in perceived length. Additionally, the golfer could use a "baseball bat swing" test, in which the golfer (optionally blindfolded) swings clubs horizontally (to avoid hitting the ground for long clubs which nevertheless "feel" short). The baseball bat swing test may either be used directly to test clubs, or may be used to help the golfer identify the "length" perception for clubs which are subsequently swung in a more traditional manner. Alternatively, the golfer can be asked to swing clubs whose ROG variation has been reduced for typical center locations, so that the difference in feel between such modified clubs and traditional clubs can be identified.

For example, suppose the ROG optimization procedure is followed with the 36" wedge and the 48" driver described above, assuming a linear relationship for tempo. Weight is added to the driver at a point, for example, 12" from the butt end of the shaft, until the clubs are perceived as having the same length. If the added weight has a mass of 178 g, the radius of gyration about a point X inches from the end of the shaft is

$$ROG(driver) = \sqrt{\frac{m_{driverhead}(\ell_{driver} - X)^2 + m_{driverweight}(p_{weight} - X)^2}{m_{driverhead} + m_{driverweight}}} \qquad \textbf{(8)}$$

where p_{weight} is the position of the added weight, in inches from the butt end of the shaft, and $m_{driverweight}$ is the mass of the added weight. (Those skilled in the art will note that the contributions of the shaft and grip to the ROG have been neglected in the above formulation, as have variations due to the fact that the club head and the added weight are not actually point masses. It will be apparent that the above formulae can easily be

modified to take these contributions into account). Thus, for the driver described, the ROG in terms of X is $\sqrt{((214g)(48-X)^2+(178g)(12-X)^2)/(214g+178g)}=\sqrt{X^2-63.3X+1320}$. In this simple model, the ROG of the wedge is simply the distance from X to the head of the wedge, in this case, 36" - X. Solving for X, we find that X = -3. (That is, the golfer's personal center is found at a point on his arms 3" above the butt end of the club), and the ROG of both clubs is 39". These parameters may then be used to weight all of the other clubs to match the ROG of the clubs about the golfer's personal center. (Added weights at the same point on the driver which would lead to determinations of X=0, X=5, or X=10 would be 187g, 208g, and 245g, respectively).

It is convenient but not necessary to start the process with the shortest club or to assume that the shortest club receives no weight. In one embodiment an arbitrary club is chosen and weight added until the golfer's swing speed begins to suffer. That is, weight is added which reduces the ROG to the minimum acceptable value for that golfer and that club. Then another club is chosen and weight added to it until the golfer feels that the second club has the same perceived length as the first. Once again the center point X can be analytically determined and the ROG calculated and used to calibrate other clubs. It is possible, however, that the calculations may call for the removal of weight from some clubs (which is usually infeasible). Additionally, the weights added in those embodiments of the invention which minimize ROG can be rather large, and may not be to the liking of all golfers, although it is believed that greater accuracy and consistency will be achievable once golfers become accustomed to the clubs of the invention.

It will be apparent to those skilled in the art that the weights need not all be placed at the same location on each club shaft, nor is it necessary to place only a single weight on the shaft. Similar calculations will apply, and the appropriate weight to be placed at any point or points on the shaft can be found for each club. If the golfer wishes all his clubs to have the same weight, this can generally be accommodated by solving for the position at which an appropriate weight should be added. It may be, however, that this position will not be on the shaft, in which case the design will have to be modified.

For example, ignoring possible weight differences of the grips and shafts, if the wedge has a head weight of 370 g, and the driver has a head weight of 214 g, a 156 g

weight can be placed on the driver shaft, and slid along the shaft until the clubs feel equal. (In the above case, mathematically this would occur when the weight is placed 3.28" from the butt end of the shaft). However, if the club head weight of the wedge is only 295 g, then there is no position where a 29 g weight can be placed on the driver to equate the ROGs. In this case, the ROGs may be equated by weighting both clubs. For example, if a 125 g weight is placed on the wedge at a position 27" from the butt end of the shaft (making the total weight 420 g), then a 206 g weight may be placed 1.7" from the butt end of the shaft of the driver to give both clubs an ROG of 36.6 and a total weight of 420 g (still using the personal center of X=-3).

In some cases, it may not be possible to equalize ROG over the entire set without the individual clubs becoming unacceptably heavy. In these cases, the ROG may be equalized for subsets of the clubs or may be made to vary in a predictable way (*e.g.*, linearly) over the set, so as to at least reduce the variation of the ROG over the set (or a subset) of clubs. "Reduced variation" in ROG, as that phrase is used herein, means a variation in ROG less than that of a set of clubs having the same club head masses and club lengths, but having no additional weights placed on the shafts.

The measurement techniques described for measurement of the ROG may also have utility in determining the "effective arm length" used in the optimization of club lengths, head weights, and lofts. The perceived center may or may not be the same for the ROG and for the centripetal force, but similar techniques involving holding all parameters but one constant and finding the closest match to a known club may be used.

It will be seen that the reduction and matching process for ROG does not change the head weight or length of the club. It can therefore easily be combined with the optimization techniques for matching tempo and perceived force described above as well as adjustments to equate design and effective loft, as described in copending and commonly assigned U.S. Patent Application No. 09/248,515.

Additional weights could be used to match the first and/or second inertial moments, either about the same center as that measured for the ROG or about a different center measured by similar methods.

The methods of the invention provide a great deal of data on optimization of golf clubs for a particular user. Given the personalized nature of the data, it may be difficult or impossible to find commercially available club heads in the style preferred by the golfer which satisfy some or all of the criteria of the invention (possibly including the criteria set forth in U.S. Patent Application No. 09/248,515). It may therefore be desirable to make club heads from scratch, and to incorporate these heads into golf clubs having desired club lengths, shaft flexibilities, grips, added weights, etc. For example, a club head can be modeled using a computer-aided design (CAD) system. The basic input to the system would be the golfer's preferred club head design, which he could either specify or choose from options already in the system. The appropriate lie, loft, head mass, lean angle (see U.S. Patent Application No. 09/248,515), and any other parameters would then be determined, and the basic design modified accordingly. (If necessary, heads may be hollow and/or made of composites in order to tailor the mass). A computer-assisted manufacturing (CAM) system can then be used to make the designed head, which may be made in multiple parts if necessary. Suitable CAM systems are commercially available which use investment casting, sand casting, electrochemical machining, electrical discharge machining, computer-controlled conventional machining systems, or other methods of forming one-of-a-kind metal items. Depending on the accuracy of the method used and the level of detail in the design, additional post-processing machining, etching, or polishing may be necessary. This method allows construction of a truly unique set of clubs, optimized for a single golfer.

Example

Table 1 shows the specification for a set of clubs optimized for the inventor. The inventor is 5'8" tall, and has an arm length of 33". The location of his personal center for ROG calculations has been determined to be 7.567" below the butt end of the shaft. His club specifications, all calculated according to the invention (*i.e.*, constant centripetal force and hand speed increasing with the square root of club length plus arm length), are as follows:

Club Length (inches)	Clubhead Weight (grams)	Club Type	Weight at 10" from shaft end (grams)	ROG (inches from *X*)	Target Distance (yards)
48	214	driver	220	28.44	250
46	225	3-wood	187	28.45	225
44	237	5-wood	153	28.44	200
42	250	4-iron	117	28.45	187.5
41⅓	254	5-iron	105	28.43	175
40⅔	259	6-iron	93	28.42	162.5
40	263	7-iron	80	28.43	150
39⅓	268	8-iron	67	28.43	137.5
38⅔	273	9-iron	54	28.43	125
38	279	wedge	41	28.43	112.5
37⅓	284	pitching wedge	27	28.45	100
36⅔	289	sand wedge	14	28.42	87.5
36	295	lob wedge	0	28.43	75

Table 1

Figure 3 plots the club lengths and club head masses specified in **Table 1**, and compares them to calculated values for a square root relationship in which $r_{tempo} = ((\ell_{club}+\ell_{arm})/(\ell_{driver}+\ell_{arm}))^{1/2}$ and $r_{force} = 1$. The shafts of these clubs are all regular flex (R) graphite shafts.

The added weights at the point 10 inches from the butt end of the shaft in the clubs described above are simply lead tape wrapped around the shaft and secured. This method of weighting the shaft has the advantage that the added mass is easily tailored and applied, but some players may prefer that some or all of the weight be added in the interior (rather than the exterior) of the shaft. It should be noted that equating the ROG over an entire set of clubs may require rather heavy weights on the longer clubs (as